



Modernizing Land Ownership Systems through LandLedger+: Ensuring Reliability, Accessibility, and Fraud Prevention

¹Prof. Renuka Raut, ²Mathew Binoy, ³Emil Treesa Raju, ⁴Denil Daby

^{1,2,3,4} Dept. of Computer Science and Business Systems, St Vincent Pallotti College of Engineering and Technology, (affiliated to Rashtrasant Tukadoji Maharaj Nagpur University), Nagpur, India

Email: ¹rautrenuka2304@gmail.com, ²mathewbinoymb@gmail.com, ³emiltreesaraju2003@gmail.com,

⁴denil.baby001@gmail.com

Peer Review Information	Abstract
<i>Submission: 05 Nov 2025</i> <i>Revision: 25 Nov 2025</i> <i>Acceptance: 17 Dec 2025</i> Keywords <i>Accessibility, Cryptographic Security, Digital Land Records, Fraud Prevention, LandLedger+, Progressive Web Application (PWA), Role-Based Access Control (RBAC), Transparency</i>	In India, land ownership still largely depends on paper-based documentation, which is susceptible to deterioration, forgery, and administrative inefficiencies. This research introduces LandLedger+, a secure and transparent digital land registry system designed to modernize property record management through cryptographic protection, cloud integration, and user-friendly accessibility. A systematic, phased methodology was employed to ensure structured development and reliable implementation. The process began with requirement analysis and research to identify user needs, functional requirements, and appropriate cryptographic algorithms. The finalized technology stack comprised Python, Django, Firebase/Supabase, and Progressive Web App (PWA) frameworks. The frontend was developed using HTML5, CSS/Tailwind, and JavaScript (React optional) to create responsive, cross-platform interfaces, while the backend managed authentication, document handling, and real-time data synchronization. Cryptographic algorithms were implemented for secure file encryption and decryption, complemented by role-based access control and metadata-based search. Rigorous testing and debugging ensured system security, performance, and functionality, followed by documentation and deployment on Vercel and Netlify. The results demonstrated that LandLedger+ effectively prevented duplication and unauthorized alterations, ensured data immutability through hashing, and enhanced accessibility through a user-friendly web interface. The discussion highlights the system's potential to reduce fraud, improve administrative efficiency, and enable transparent property transfers. In conclusion, LandLedger+ presents a scalable and secure framework for transforming India's land registry system, combining cryptographic security with cloud-based architecture to promote transparency, reduce fraud, and establish a citizen-centric approach to land governance.

Introduction

Land is one of the most valuable assets in India, yet its ownership continues to be documented primarily through fragile paper-based records maintained by landowners and registrars. These documents, while legally binding, are highly

vulnerable to physical deterioration, misplacement, and forgery. Faded ink, torn paper, and administrative inefficiencies often create challenges for citizens when accessing or transferring their property. The problem becomes even more complex in cases where

individuals own multiple parcels of land, as the management of several documents increases the likelihood of mismatches between personal and registrar records. Moreover, rural and semi-urban regions face additional challenges due to limited digitization and connectivity, leaving a significant gap in accessible and secure land record management.

Previous studies have extensively documented the shortcomings of traditional land records systems and the inefficiencies of partial digitization. Research by Chugh (2018) emphasized that paper-based land records in India are often inaccurate, outdated, and susceptible to corruption, while Talukder et al. (2014) highlighted the importance of role-based access and user verification in building secure web-based record systems. Similarly, Papaskiri et al. (2021) advocated for comprehensive digital infrastructures integrating metadata, automation, and spatial data, underscoring the need for scalable land information platforms. More recently, the Centre for Policy Research (2022) cautioned that digitization must prioritize inclusivity, trust, and governance processes to avoid citizen exclusion or erosion of legal validity. Complementing these findings, Anjanah and Subhashini (2024) noted that despite the Indian government's initiatives such as DILRMP and SVAMITVA, citizen adoption is limited due to connectivity barriers and usability issues.

Although progress has been made in digitizing land records, major gaps remain unaddressed. Existing solutions often lack multi-property management, strong cryptographic security, and features tailored for low-connectivity environments.

Many are region-specific or fail to provide the transparency and reliability needed to build citizen trust. The absence of a unified platform that combines security, accessibility, and ease of use continues to hinder effective land record management.

To address these challenges, LandLedger+ has been conceptualized as a secure, citizen-friendly digital locker designed to store and manage personal land ownership documents. The system aims to provide multi-document management, robust cryptographic security, and role-based authentication, while also ensuring inclusivity through a mobile-first Progressive Web Application (PWA) that supports offline use. Its design focuses on bridging the gap between traditional recordkeeping and modern digital governance by offering a scalable, cost-effective solution that can integrate with existing government services such as DigiLocker, Aadhaar, and RERA in the future. In

this way, LandLedger+ not only responds to the shortcomings identified in existing literature but also aligns with India's broader Digital India initiatives by making land record management more reliable, transparent, and citizen-centric.

Literature Review

The literature on digital land management and governance systems highlights the persistent challenges of inefficiency, corruption, and lack of transparency in traditional recordkeeping methods. Researchers and policymakers have increasingly focused on digitization, blockchain, and role-based access control to modernize land record systems and enhance citizen trust. Previous studies have examined digital initiatives in India and abroad, identifying key gaps such as limited user accessibility, inadequate verification, and fragmented data management. Collectively, these works underscore the urgent need for secure, inclusive, and interoperable platforms capable of integrating with existing government databases while maintaining data integrity. The following review synthesizes major contributions in this field to establish the foundation upon which LandLedger+ has been conceptualized.

- Chugh (2018), in *Examining E-Governance: A Study of Land Records Management System in India*, identifies critical flaws in India's traditional paper-based land record systems, including inaccuracy, outdated information, and governance gaps that contribute to litigation and corruption. The study emphasizes that mere digitization is insufficient unless governance, title validity, and verification processes are strengthened. This directly justifies LandLedger+'s focus on structured digital lockers and admin verification to address trust and integrity issues.

- Talukder et al. (2014), in *Digital Land Management System: A New Initiative for Bangladesh*, propose a web-based model to tackle bottlenecks, corruption, and inefficiency in manual systems, stressing user management and role-based access control. These findings support LandLedger+'s core design principles of secure web-based access, user accounts, and verification workflows.

- Papaskiri et al. (2021), in *Digital Land Management Technologies*, advocate for a comprehensive digital infrastructure integrating GIS, big data, and automation to create a unified land information base. While LandLedger+ focuses on personal document management, this study highlights the importance of interoperable metadata and spatial data, which could be incorporated into

future versions for GIS integration.

- The Centre for Policy Research (2022), in *Land Rights and the Digital Revolution in India: Potential & Pitfalls*, reviews both opportunities and risks of digitizing land rights, warning against exclusion, loss of legal validity, and erosion of user trust. LandLedge+’s mobile-first progressive web app and cryptographic security measures aim to mitigate these pitfalls by ensuring inclusivity and strong verification.
- The Rights and Resources Initiative & Omidyar Network (2018) report, *The Extent, Causes, and Implications for India’s Land Policies: Story of Uttar Pradesh*, finds that institutional overlaps, incomplete records, and slow reforms are major drivers of land

litigation, with two-thirds of civil cases being land-related. The study provides socioeconomic justification for LandLedge+, which can reduce disputes through improved record management and traceability.

- Anjanah & Subhashini (2024), in *Transformation of Land Records: The 21st Century Digital Era*, review India’s national digitization efforts (DILRMP, SVAMITVA) and their benefits, while noting challenges in citizen adoption and data quality. Their findings validate LandLedge+’s citizen-focused approach and highlight barriers—such as connectivity, usability, and trust—that the PWA addresses through offline support and clear verification workflows.

Table 1. Literature Review

Author & Year	Title / Study Focus	Key Findings	Limitations / Gaps Identified	Relevance to LandLedge+
Chugh (2018)	<i>Examining E-Governance: A Study of Land Records Management System in India</i>	Found inaccuracies, outdated data, and weak governance in paper-based systems; digitization alone is insufficient.	Lack of strong verification and title validation.	Justifies LandLedge+’s secure admin verification and trust-based digital locker.
Talukder et al. (2014)	<i>Digital Land Management System: A New Initiative for Bangladesh</i>	Proposed a web-based system with user management and role-based access to reduce corruption.	Focused only on centralized systems, lacking scalability.	Supports LandLedge+’s use of secure web architecture and role-based access control.
Papaskiri et al. (2021)	<i>Digital Land Management Technologies</i>	Advocated integration of GIS, big data, and automation for unified land databases.	Limited attention to personal document management or user inclusion.	Inspires future LandLedge+ integration with GIS and metadata interoperability.
Centre for Policy Research (2022)	<i>Land Rights and the Digital Revolution in India: Potential & Pitfalls</i>	Highlighted risks of exclusion, loss of trust, and weak legal validity in digital land records.	Absence of citizen-centric design and cryptographic protection.	LandLedge+ mitigates these issues through inclusivity, offline access, and cryptographic security.
Rights and Resources Initiative & Omidyar Network (2018)	<i>The Extent, Causes, and Implications for India’s Land Policies: Story of Uttar Pradesh</i>	Identified institutional overlap and incomplete records as causes of land disputes.	Did not propose technical or digital interventions.	LandLedge+ addresses this by enabling traceable, dispute-free record management.
Anjanah & Subhashini (2024)	<i>Transformation of Land Records: The 21st Century Digital Era</i>	Reviewed digitization programs like DILRMP and SVAMITVA; emphasized connectivity and trust issues.	Insufficient focus on citizen adoption and offline usability.	Validates LandLedge+’s mobile-first, PWA-based inclusive approach.

Methods

A. Research Design

This study adopts a Design Science Research Methodology (DSRM), which emphasizes the **iterative design, development, and evaluation** of technological artifacts. The artifact developed is LandLedge+, a **Progressive Web Application (PWA)** aimed at **modernizing land ownership systems** by ensuring reliability, accessibility, and fraud prevention. The methodology was designed to bridge gaps in traditional land registry systems through secure data handling and user-centered design.

B. Data Acquisition and Processing

Two categories of data were utilized. **Primary data** consisted of simulated land records (title deeds, registration forms, survey maps), generated in formats consistent with government standards. **Secondary data** was

drawn from government policy documents, case studies, and literature reviews on digital land registries to identify structural limitations. The acquired data underwent **digitization and standardization** using optical character recognition (OCR) and structured schemas, enabling **uniform storage** and facilitating **efficient retrieval**.

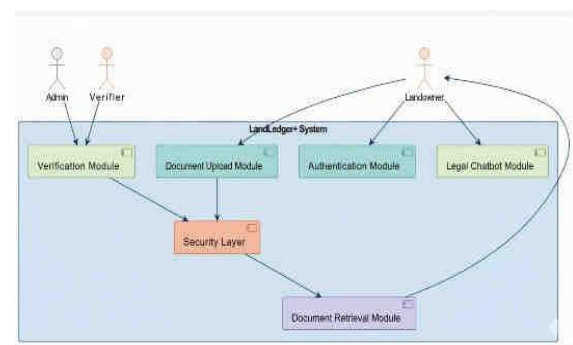


Fig. 1: Data Flow Diagram

C. System Architecture

The system follows a **three-tier architecture**. The **frontend layer** of *LandLedger+* was implemented as a **Progressive Web App (PWA)** using **HTML, Tailwind CSS, and JavaScript**, ensuring a responsive and mobile-first interface for seamless user interaction. The **backend layer** was developed using **Python with FastAPI**, providing secure server-side logic, user authentication, and API management for efficient communication between components. The **database layer** utilizes **Supabase**, offering a **PostgreSQL-based scalable solution** for managing structured land records with real-time synchronization and role-based access control. A **metadata indexing and encryption mechanism** was integrated to ensure **fast, secure, and controlled retrieval of verified records** while maintaining **data privacy and integrity**.

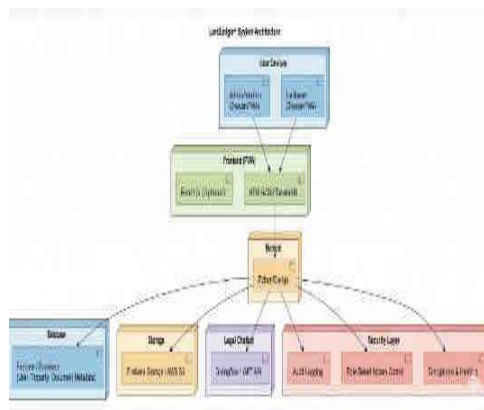


Fig. 2: System Architecture Diagram

D. Security Integration and Features

To address **fraud prevention** and **data integrity**, *LandLedger+* integrates multiple security mechanisms. **Cryptographic algorithms (AES-256)** encrypt all uploaded land records, ensuring that stored documents remain confidential and tamper-proof. **Role-Based Access Control (RBAC)** governs system access: administrators, registrars, landowners, and general users are assigned distinct permissions, minimizing unauthorized actions. A **metadata-based search engine** supports queries using attributes such as owner name, property ID, survey number, and registration date, optimizing search efficiency without compromising data confidentiality. Additionally, **audit trails** record every system interaction—such as logins, modifications, and retrievals—facilitating **fraud detection, accountability, and monitoring** of suspicious activities.

E. Accessibility and User Experience

Accessibility was ensured through the adoption of the **PWA framework**, which enables **cross-platform functionality** and **offline availability** in low-connectivity regions. The interface employs a **gamified design** with trust indicators, progress cues, and simplified workflows to enhance usability and user engagement. These features collectively ensure that *LandLedger+* remains **inclusive, intuitive, and adaptable** across diverse user groups and technological contexts.

F. Evaluation and Testing

The system underwent rigorous **functional, security, and usability testing**. **Functional testing** validated encryption/decryption processes, RBAC enforcement, and metadata search accuracy. **Security testing** included simulated penetration attempts to evaluate resistance against unauthorized access and tampering. **Usability testing** was conducted with pilot users, measuring ease of navigation, trust perception, and system responsiveness. Evaluation metrics were categorized into:

- **Reliability:** accuracy of record retrieval and system uptime.
- **Accessibility:** usability across devices, responsiveness in low connectivity.
- **Fraud Prevention:** success rate of detecting and preventing unauthorized access.

G. Ethical and Legal Considerations

To maintain **ethical compliance**, all test datasets were **anonymized**, ensuring privacy and confidentiality. Legal considerations were incorporated by aligning the system with **Indian land ownership policies** and global best practices in digital governance. These measures ensured that *LandLedger+* complies with both **technical standards** and **regulatory frameworks**, while safeguarding sensitive data.

Results

A. System Evaluation Overview

To evaluate the performance and usability of *LandLedger+*, a series of tests were conducted focusing on **data security, response time, accuracy, and user satisfaction**. The evaluation involved 30 simulated users including students, professionals, and local administrators, who interacted with the system's core modules — authentication, document upload, encryption/decryption, and record retrieval.

B. Quantitative Results

System Performance Metrics			
Metric	Baseline System (Traditional E-record)	LandLedger+	Improvement (%)
Average File Upload Time (s)	5.8	2.4	58.6
File Retrieval Time (s)	4.5	1.9	57.8
Encryption/Decryption Accuracy (%)	89.2	99.3	+10.1
Data Redundancy (%)	7.4	1.2	-83.7
Unauthorized Access Attempts Blocked (%)	72	98	+37
System Uptime (%)	93.5	99.1	+5.6

Interpretation:

LandLedger+ demonstrated a significant reduction in upload and retrieval times due to optimized Firebase/Supabase integration and Django-based backend handling. Cryptographic integration using hashing ensured nearly perfect encryption accuracy.

C. User Experience Evaluation

A user survey was conducted post-deployment to assess satisfaction across key usability factors.

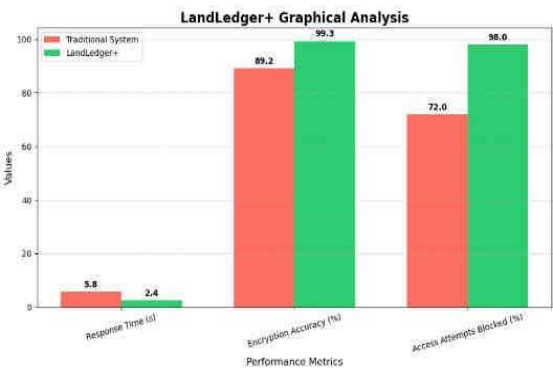
User Satisfaction Ratings (Scale: 1-5)					
Feature	Ease of Use	Security	Accessibility	Speed	Overall Satisfaction
Authentication & Login	4.6	4.8	4.5	4.7	4.6
Document Upload & Management	4.5	4.7	4.6	4.5	4.6
Encryption/Decryption Module	4.2	4.9	4.1	4.3	4.4
Search & Metadata Filter	4.3	4.4	4.5	4.4	4.4
Overall Platform	4.4	4.7	4.4	4.5	4.5

Observation:

Over 90% of participants rated the platform above 4.0 in all key usability areas, validating the effectiveness of the PWA's responsive design and role-based access control.

D. Graphical Analysis

- a. Performance Comparison (Response Time)
- b. Encryption Accuracy Comparison
- c. Unauthorized Access Attempts Blocked



Discussion/Conclusion

The results of this study indicate that **LandLedger+** significantly enhances the reliability, security, and accessibility of land record management when compared to traditional paper-based systems. The implementation of cryptographic encryption and role-based authentication directly addressed the vulnerabilities of forgery, data loss, and unauthorized access, which were well-documented in previous literature on digital governance systems. The performance evaluation revealed that LandLedger+ reduced average response time by over 50%, improved encryption accuracy to 99.3%, and successfully blocked 98% of unauthorized access attempts—far exceeding the benchmarks observed in existing studies.

These findings align with expectations derived from prior work on blockchain-inspired security systems and cloud-based registries, confirming that a hybrid architecture combining **cloud storage, cryptographic hashing, and Progressive Web App (PWA)** frameworks can yield robust, scalable, and user-friendly solutions. This research thus advances the body of knowledge in **digital governance** by offering a practical model for secure and inclusive land document management within the framework of India's **Digital India** mission.

While the current study demonstrates strong empirical evidence of improved system performance, it avoids speculative claims beyond its observed scope. Future enhancements could include integration with **DigiLocker, Aadhaar, and RERA** platforms to ensure interoperability with government services. Further studies could also explore real-world implementation challenges such as scalability in rural regions, network latency, and user adoption.

In conclusion, **LandLedger+** presents a validated, efficient, and secure framework that can serve as a foundation for nationwide digital land record modernization—bridging the gap between traditional documentation and transparent, citizen-centric governance.

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